

**CERTIFICATION OF AIRCRAFT ELECTRICAL/ELECTRONIC
SYSTEMS FOR THE INDIRECT EFFECTS OF LIGHTNING**

FINAL

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NOTE: Whenever a reference document appears in this AC/AMJ, it carries the minimum revision level of the reference document acceptable to meet the intended requirements. Later versions of the reference document are also acceptable but earlier versions are not acceptable. In all cases, other documents shown to be equivalent to the referenced document are also acceptable.

1. PURPOSE. This AC/AMJ provides information and guidance concerning a means, but not the only means, of compliance with Parts 23, 25, 27, and 29 of the Federal Aviation Regulations (FAR) and Joint Airworthiness Requirements (JAR), as applicable for preventing hazards, due to lightning indirect effects, from occurring to electrical/electronic systems.
2. SCOPE. This AC/AMJ provides guidance for a means of showing compliance with the regulations for hazards caused by the lightning environment to electrical/electronic systems installed either on or within aircraft. Equipment hazards addressed include those due to indirect effects on equipment and its associated wiring that is mounted on the aircraft exterior as well as indirect effects on equipment and its associated wiring located within the aircraft interior. This document applies to new aircraft and equipment designs, modifications of existing aircraft or equipment, and applications of existing (off the shelf) equipment on new aircraft.

Note: This AC/AMJ does not address direct effects such as burning, eroding, blasting, of aircraft structure nor does it address fuel ignition hazards (see related reading material in Section 4 of this document). This AC/AMJ does not address lightning zoning methods or lightning test requirements, methods, and techniques. Coverings (fairing, skin, cowl, etc.) should normally prevent direct attachment of the lightning channel to underlying system components. However, if a direct lightning strike attachment to a system component can occur, a complete evaluation of both direct and indirect effects will be necessary.

It should be noted that electrical/electronic systems or components

are sometimes exposed to lightning currents directly conducted from the aircraft exterior, as may happen when an antenna is struck and a portion of lightning current flows in its cable. Care should be taken to identify any such possibilities and either eliminate these situations by design modifications, or address them in the certification plan. No further discussion of these situations is included in this AC/AMJ.

3. RELATED FAR and JAR INFORMATION.

- a. Federal Aviation Regulations (FAR). Federal Aviation Regulations 14 CFR Parts 23, 25, 27, 29 and 33; Sections .901, .903, .1301, .1309, .1316, .1431, and .1529 (as applicable). 14 CFR Part 33, Sections .28 and .91 (as applicable).
- b. FAA Advisory Circulars. The following Advisory Circulars (AC) may provide additional information.
 - (1) AC 23.1309-1B, System and Equipment Installations in Part 23 Airplanes, dated July 28, 1995.
 - (2) AC 25.1309-1A, System Design and Analysis, dated June 21, 1988.
 - (3) AC 27-1, Certification of Normal Category Rotorcraft, dated August 8, 1985, including to Change 4 dated August 18, 1995.
 - (4) AC 29-2A, Certification of Transport Category Rotorcraft, dated September 16, 1987, including to Change 3 dated June 1, 1995.
 - (5) AC 21-16C, Radio Technical Commission for Aeronautics Document DO-160D, dated March, 1998.
 - (6) AC 20-TBD, Aircraft Lightning Zoning
 - (7) AC 20-TBD, Aircraft Lightning Environment and Related Test Waveforms
- c. Joint Airworthiness Requirements (JAR). Joint Airworthiness Requirements Parts 23.1309, 25X899, 25.1309, 25.1431, 27.610, 27.1309, 29.610, 29.1431, JAR E AMJ 20X-1.

d. JAA Advisory and Interpretive Material.

- (1) ACJ 25X899. *Electrical Bonding and Protection Against Lightning and Static Electricity (Interpretive Material and Acceptable Means of Compliance).*
- (2) ACJ 29.610. *Lightning and Static Electricity Protection (Interpretive Material and Acceptable Means of Compliance).*
- (3) AMJ 20X-1. *Certification of Aircraft Propulsion Systems Equipped with Electronic Controls.*
- (4) AMJ 25.1309. *System Design and Analysis*
- (5) AMJ 29.1309. *Equipment, System and Installation*
- (6) AMJ 20.TBD. *Aircraft Lightning Zoning*
- (7) AMJ 20.TBD. *Aircraft Lightning Environment and Related-Test Waveforms*

4. RELATED READING MATERIAL. A comprehensive discussion on the material in this AC/AMJ, with additional guidance information, is available in the following documents:

a. EUROCAE Documents.

- (1) **EUROCAE ED-14D. Environmental Conditions and Test Procedures for Airborne Equipment. dated July 1997**

b. RTCA, Inc., Documents. These documents are available from RTCA, Inc., 1140 Connecticut Avenue, NW, Suite 1020, Washington, DC 20036-4001:

- (1) **RTCA, Inc., DO-160D. Environmental Conditions and Test Procedures for Airborne Equipment. dated July, 1997**

- c. SAE Documents. These documents are available from the Society of Automotive Engineers, Inc., (SAE), 400 Commonwealth Drive, Warrendale, PA 15096:
 - (1) Aerospace Recommended Practice (ARP) 4754, Certification Considerations for Highly Integrated or Complex Aircraft Systems.
- d. SAE/EUROCAE Joint Documents.
 - (1) User's Manual for this AC/AMJ.
 - (2) Aircraft Lightning Test Standard.
- 5. BACKGROUND
 - a. Aircraft electrical/electronic systems may be vulnerable to lightning hazards. Aircraft which utilize an increasing number of electrical/electronic systems are currently being and will continue to be certified.
 - b. Lightning indirect effects may result when the electromagnetic fields produced by a direct strike to the aircraft induce voltage and current transients into the electrical/electronic equipment or components. These transients can be produced by electromagnetic field penetration into the aircraft interior or by structural IR (current times resistance) voltage rises due to current flow on the aircraft. Physical damage (direct effects) can also result from a direct lightning attachment to the aircraft.
 - c. The trend toward increased reliance on electrical/electronic systems for flight and engine control functions, navigation, and instrumentation requires that effective protection against lightning induced transients be designed and incorporated into these systems. Reliance upon redundancy as a sole means of protection against lightning indirect effects is generally not adequate because the electromagnetic fields and structural IR voltages can interact concurrently with all electrical

wiring aboard an aircraft.

6. DEFINITIONS. See Appendix I for list of Definitions.

7. APPROACHES TO COMPLIANCE. The following seven (7) activities are elements of an iterative process for certification of aircraft electrical/electronic systems with respect to the indirect effects of lightning. The particular order of activities addressed, and the iterative application of the elements appropriate for a particular situation, are left to the applicant and strict adherence to the particular ordering of the elements in the list is not intended.

- a. Review the safety analysis with respect to the indirect effects of lightning on the aircraft.
- b. Determine the lightning strike zones for the aircraft.
- c. Establish the airframe lightning current paths for the zones.
- d. Establish the effects of the internal environment.
- e. Establish Transient Control Levels (TCL) and Equipment Transient Design Levels (ETDL).
- f. Verify Compliance.
- g. Corrective Measures.

The elements are described in more detail in paragraphs (a) through (g).

- a. Review the safety analysis with respect to the indirect effects of lightning. A Functional Hazard Assessment (FHA) is conducted to identify all failures and classify them in functional and operational terms. The results of the FHA should be reviewed to ensure that any unique indirect effects of lightning have been identified, such as common mode failures. Airworthiness requirements for classifying these functions are based on Section .1309 of FAR/JAR Parts 23, 25, 27, and 29. FAA/JAA advisory circulars which provide guidance in classifying these failure conditions according to their severity are as follows: AC 23.1309-1B, 25.1309-1A, 27-1.29-2A, AMJ 25.1309 and ACJ 29.1309.

The failure condition classifications listed below are derived from this guidance material and are included to assist in the use of this document. The classifications are:

(1) Catastrophic: Failure conditions which would prevent continued safe flight and landing.

(2) Hazardous/Severe-Major: Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be:

- (i) A large reduction in safety margins or functional capabilities.
- (ii) Physical distress or higher workload such that the flight crew could not be relied on to perform their tasks accurately or completely, or
- (iii) Serious (or fatal*) injury to a relatively small number of the occupants.

* JAA only

(3) Major: Failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew work load or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries.

(4) Minor: Failure conditions which would not significantly reduce aircraft safety, and which involve crew actions that are well within their capabilities. Minor failure conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some inconvenience to occupants.

(5) No Effects: Failure conditions which do not affect the operational capability of the aircraft or increase crew workload.

The system development assurance level would also be assessed when performing the FHA and would be approved by the cognizant aviation certification authority. Guidance for selecting the system development assurance level is provided in SAE ARP 4754.

The following development assurance levels are related to the failure condition classifications.

- Level A: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a catastrophic failure condition for the aircraft.
- Level B: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a hazardous/severe-major failure condition for the aircraft.
- Level C: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a major failure condition for the aircraft.
- Level D: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a minor failure condition for the aircraft. Once a system has been confirmed, by the cognizant aviation certification authority, as being Level D, no further application of this regulation is required.
- Level E: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in no effect on aircraft operational capability or crew workload. Once a system has been confirmed, by the cognizant aviation certification authority, as being Level E, no further application of this regulation is required.

- b. Determine the lightning strike zones for the aircraft. The characteristics of currents entering the aircraft vary according to attachment point locations on the aircraft. To establish the lightning characteristics appropriate for different portions of the aircraft, lightning strike zones have been defined in the AC/AMJ 20-TBD Aircraft Lightning Zoning.

Zones are the means by which the external environment is applied to the aircraft. The locations of these zones on any aircraft are dependent on the aircraft's geometry, materials, and operational factors, and often vary from one aircraft type to another; therefore, a determination must be made for each aircraft configuration. Guidance for location of the strike zones on particular aircraft is given in the AC/AMJ 20-TBD. Aircraft Lightning Zoning.

- c. Establish the airframe lightning current paths for the zones. The external lightning environment is a consequence of the interaction of the lightning flash with the exterior of the aircraft. The external environment is represented by synthesized waveforms of the lightning current components at the aircraft surface. These waveforms and their applications are provided in the AC/AMJ 20-TBD. Aircraft Lightning Environment and Related Test Waveform.

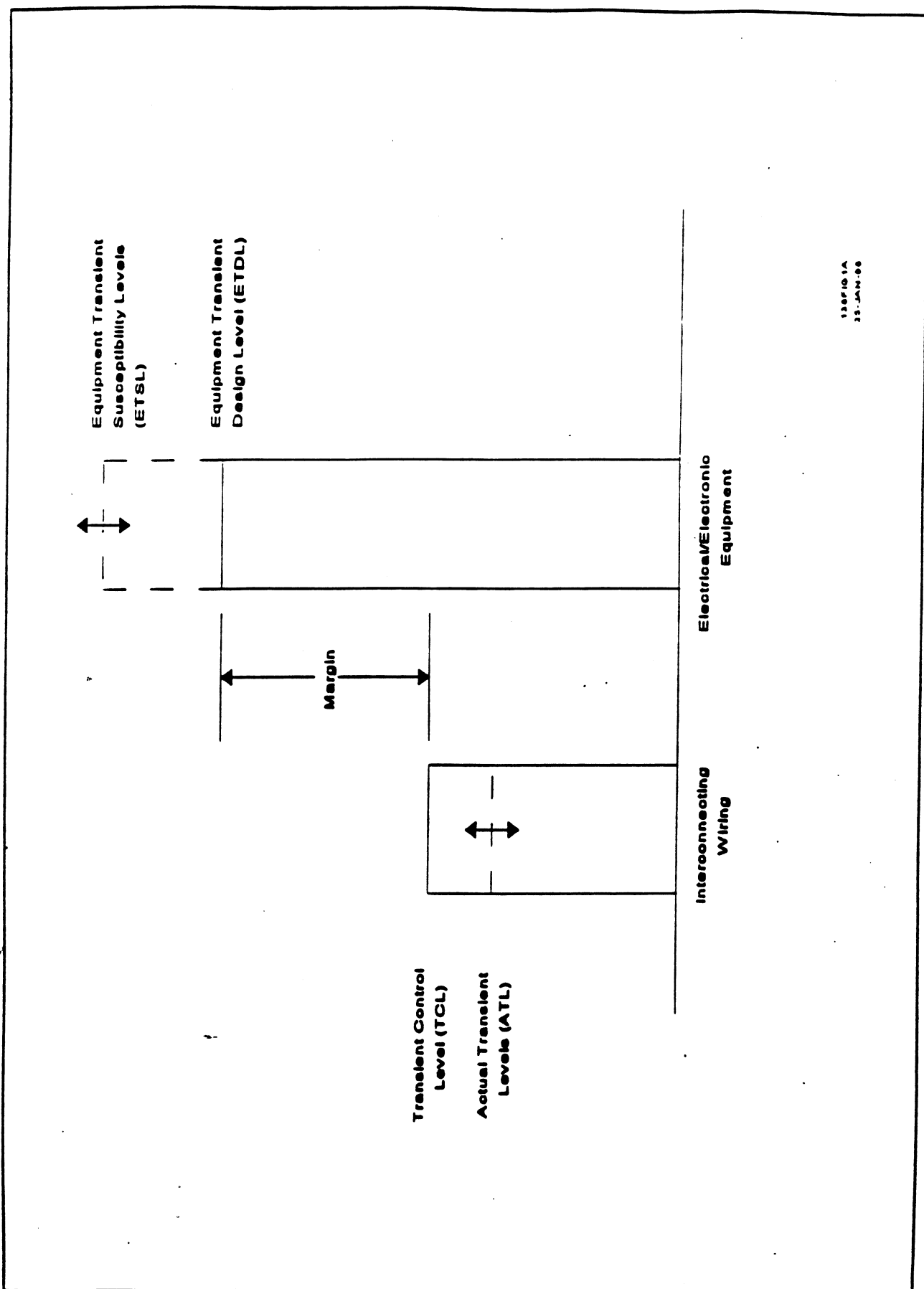
Zones 1 and 2 define where lightning is likely to attach, and, as a result, the entrance and exit points for current flow through the vehicle. By definition, Zone 3 areas carry lightning current flow between pairs of direct or swept stroke lightning attachment points. Therefore, design and analysis using Zone 3 current levels as the external environment is generally acceptable.

- d. Establish the effects of the internal environment. The internal lightning environment consists of the electromagnetic fields and structural IR voltages, which are produced by the external environment, as a result of current flow through the airframe and the penetration of electromagnetic fields. The fields and structural IR voltages cause voltages and currents on interconnecting wiring which in turn appear at equipment interfaces. In some cases, electromagnetic fields within the aircraft may penetrate equipment enclosures and compromise system operation.

For each system to be qualified, determine the lightning induced voltage and current waveforms and actual transient levels (ATL) that can appear at the electrical/electronic equipment interfaces. In many cases, the induced

transients will be defined in terms of the open circuit voltage (v_{∞}) and the short circuit current (i_{sc}) appearing at wiring/equipment interfaces. The "v" and "i" will be related by the source impedances (i.e., loop impedance) of interconnecting wiring, and there may be different levels determined for different circuit functions or operating voltages.

- e. Establish transient control levels (TCL) and equipment transient design levels (ETDL). The ETDLs represent the amplitude of voltage and/or current that the equipment is required to withstand or tolerate and remain operational (e.g., no damage or system functional upset). The TCLs, in turn, are set equal to or higher than the maximum ATL. The difference between ETDL and TCL is the margin. The equipment transient susceptibility level (ETSL) is the amplitude of voltage or current which, when applied to the equipment, will result in damage to components, or upset such that the equipment can no longer perform its intended function. The relationship between ATLs, TCLs, ETDLs, and ETSLs is illustrated in Figure 1. The ETDL is usually stated in the specifications for electrical/electronic equipment and constitutes a qualification test level for this equipment. Since ETDLs are typically represented by these standardized requirements, their use greatly simplifies compliance evaluation. Normally, the TCLs and ETDLs will be established by the airframe manufacturer or system integrator, who will compare the penalties of vehicle or interconnecting wiring protection or equipment hardening to establish the most logical combination of TCLs and ETDLs.



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Figure 1 - Relationships Between Transient Levels

- f. Verify compliance. Verify compliance by demonstrating that the ATLs appearing at wiring/equipment interfaces do not exceed the established TCLs, and that the equipment can tolerate the ETDs.
- (1) Verification may be accomplished by demonstrating similarity with previously installed systems and/or equipment, by tests, or by analysis. Appropriate margins to account for uncertainties in the verification techniques may be required as discussed in Section 9. Developmental test data may be used for certification when properly documented and coordinated with the cognizant aviation certification authority.
 - (2) Experience has shown, particularly on aircraft with new technology and/or complex systems, that discussion of and concurrence with the certification plan by the cognizant aviation certification authority early in the program is desirable. This plan is beneficial to both the applicant and the cognizant aviation certification authority because it identifies and defines an acceptable resolution of the critical issues early in the certification process. It should be understood that, as the process proceeds, analysis or test results may warrant modifications in design and/or verification methods. As necessary, when significant changes occur, the plan should be updated. The plan may include the following items:
 - (i) A description of the system(s), its installation configuration including any unusual or unique features, the operational aspects being addressed, zone locations, lightning environment, and preliminary estimate of ETD/TCLs.
 - (ii) A description of the method to be used to verify compliance. Typically, the verification method includes a combination of similarity, analytical procedures, and/or tests. If analytical procedures are used, the methodology for verification of these procedures should be described. For further discussion see Section 10.
 - (iii) Acceptance Criteria for each system under consideration should be determined by a safety analysis. This safety analysis is to

evaluate the aircraft in its various operational situations, taking into account the failure and disruption modes caused by lightning indirect effects.

- (iv) Test Plans for each test should be prepared when tests are to be a part of the certification process. Test plans can be separate documents or a part of the compliance plan at the applicant's option and should address an appropriate test sequence.

- g. Corrective Measures. When test and/or analysis show that acceptance criteria are not achieved, a review of the installation and/or component design should be conducted to determine where lightning protection methodology can be improved. The approach is to optimize the use of installation design techniques and equipment design.

8. EFFECTS OF INDUCED TRANSIENTS. Induced transients may be characterized by voltages impressed across or currents flowing into equipment interfaces. Equipment interface circuit impedance(s) and configuration(s) will determine whether the induced transient(s) are predominantly voltage or current. These transient voltages and currents can degrade system performance permanently or temporarily. Component damage and system functional upset are the primary types of degradation. Component damage is a permanent condition while functional upset refers to an impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state which may or may not require manual reset), which may adversely affect flight safety.

- a. Component Damage. Devices which may be susceptible to damage due to electrical transients are (1) active electronic devices, especially high frequency transistors, integrated circuits, microwave diodes and power supply components, (2) passive electrical and electronic components, especially those of very low power or voltage rating; (3) electro-explosive devices such as squibs and detonators, (4) electromechanical devices such as indicators, actuators, relays, and motors, and (5) insulating materials (e.g., insulating materials used in printed circuit boards and connectors) and electrical connections which can be burned or melted.

- b. System Functional Upset. Functional upset is primarily a system problem. Permanent or momentary upset of a signal, circuit, or a system component can adversely affect system performance to a degree which compromises flight safety. In general, functional upset depends on circuit design and operating voltages, signal characteristics and timing, and system and software configuration. Systems or devices which may be susceptible to functional upset due to electrical transients include (1) computers and data or signal processing systems, (2) electronic engine and flight controls, and (3) power generating and distribution systems.

9. MARGINS AND VERIFICATION METHODS. Margins are incorporated to account for the uncertainties involved in the verification process. The magnitude of the margin required is inversely proportional to the confidence which is placed in the verification methods being used. The magnitude of the margin is also directly proportional to the degree that each system contributes to continued safe flight and landing as determined by the aircraft safety analysis. An acceptable margin is an essential element in the compliance process.

10. MAJOR ELEMENTS OF COMPLIANCE. Various methods for the establishment of TCLs and ETDs (7e), verification of compliance (7f), and corrective measures (7g) are available. These methods, testing, analysis, and similarity, are outlined in the following sections. The methods outlined represent those which have evidence of practical application. The routes to compliance for Level A Control, Level A Display, and Levels B and C systems are provided in the flow diagrams of Figures 2, 3, and 4. It should be noted that there is a corresponding increase in the rigor of compliance with an increase in the failure condition classification of the function performed by the system/equipment.

Note:

Control System failures and malfunctions can more directly and abruptly contribute to a catastrophic event than display system failures and malfunctions. Based upon this, it is appropriate to require a more rigorous verification method for Level A Control Systems than for Level A Display Systems.

- a. Level A Requirements

The translation of the external environment into the internal environment involves application of elements b., c., and d., delineated in Section 7. These activities, as well as those associated with the translation of the internal environment into the equipment interface currents and voltages, comprise the system level assessment of the aircraft electromagnetic (EM) response to a lightning strike and are associated with showing compliance of Level A systems.

Functions performed by electrical and electronic systems whose failure to provide that function correctly could lead to a catastrophic failure condition, would require protection to the extent that the function must not be adversely affected when the aircraft is exposed to lightning. These functions must continue to be provided during and after exposure to lightning.

If the function is provided by multiple systems, then loss of a system or systems, during exposure of the aircraft to lightning shall not result in the loss of the function. After the aircraft is exposed to lightning, each affected system that performs these functions shall automatically recover normal operation, unless this conflicts with other operational or functional requirements of that system.

Any Failure or Malfunction which occurs during the qualification process must be considered in the overall safety assessment

(1) Systems Performing Level A Control Functions

The applicant must demonstrate that systems performing Level A Control functions are not adversely affected by a lightning strike to the aircraft in which the systems are installed. The Level A Control function must be maintained during and after exposure to lightning.

Figure 2 is a flow diagram showing possible routes to compliance. In all cases, data from aircraft level test or analysis of the specific aircraft under consideration or one of sufficiently similar construction is necessary to obtain certification.

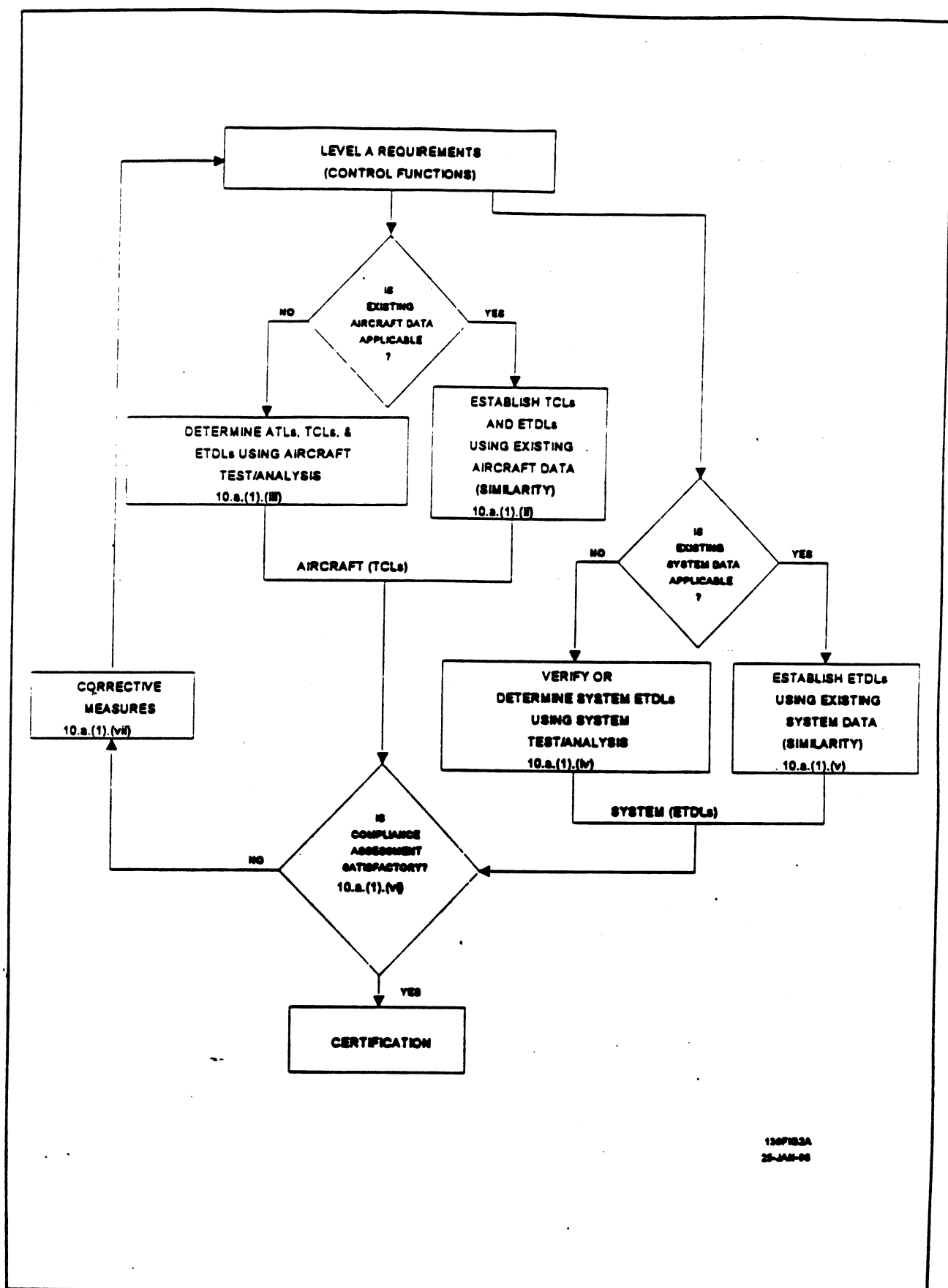
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Figure 2 - Typical Iterative Process for Level A Requirements (Control Functions)

(i) Similarity

Similarity may be used as the basis for certification without the need for additional tests provided:

- only minimal differences exist between the previously certified system and installation and the system and installation to be certified, and
- there have been no unresolved in-service history of problems related to lightning strikes to the aircraft.

If there is uncertainty about the effects of the differences, additional tests and/or analysis should be conducted as necessary and appropriate to resolve the open issues.

Similarity may be used to verify compatibility of systems and equipment with ETDs, or compatibility of interconnecting wiring with TCLs. The former situation might occur when a previously tested system is to be certified in a new aircraft, and the latter situation may occur when a new system is to be installed in an existing aircraft using interconnecting wiring for which ATLs and TCLs are known.

Similarity requires an evaluation of both the system and installation differences which may adversely affect the system susceptibility. An assessment of a new installation should consider differences affecting the internal lightning environment of the aircraft and its effects on the system. The assessment may cover:

- (A) the aircraft type, equipment locations, airframe construction, and apertures which could affect attenuation of the external lightning environment;
- (B) the system interfaces, wiring size and routing, connectors, whether parallel or twisted wires, and cable shielding;
- (C) grounding and bonding;
- (D) system modification status including software, firmware, and hardware.

Systems previously certified by test or analysis may be transferable to other applications. Every system needs to be assessed even though it may utilize equipment and installation techniques which have been the subject of a previous certification.

The use of similarity for Level A Control systems requires that the applicant show that any differences of either the system or its installation cause NO ADVERSE CHANGES on the TCL and ETDL values.

Similarity is NOT APPLICABLE for a combination of a new aircraft design and a new system design.

(ii) Establish TCLs and ETDLs Using Existing Aircraft Data (Similarity)

Existing aircraft data generated by test and/or analysis may be used to establish TCLs provided the aircraft and system installation under consideration are similar to the aircraft and system installation used to generate the data. Guidance in determining aircraft similarity is given in Section 10.a.(1).(i).

(iii) Determine ATLS, TCLs, and ETDLs Using Aircraft Test/Analysis

The ATLS, TCLs, and ETDLs may be determined by aircraft test and/or analysis. Guidance for performing tests is contained in the Aircraft Lightning Test Standard and guidance for performing analysis is contained in the User's Manual.

Analysis is a valid method for obtaining ATLS. Methods are available for full 3D simulations of entire aircraft including the internal structure and cables. In order to be accepted by the cognizant aviation certification authority, the methods' accuracy must be demonstrated. Some methods have been validated with experimental data under a wide variety of circumstances.

(iv) Verify or Determine System ETDLs Using System Test/Analysis

The ETDLs provided by aircraft test and/or analysis are used for single stroke, multiple stroke, and multiple burst testing. For

multiple stroke and multiple burst testing, the system should be tested in accordance with procedures described in the Aircraft Lightning Test Standard. For pin and single stroke cable bundle testing, the system should be tested in accordance with procedures described in DO-160D/ED-14D, Section 22. Whenever cable bundle test methods are used, the system should be tested in an operational state.

Multiple stroke and multiple burst testing to the ETDs or an analysis of the circuit response to these environments is required. When an analysis is performed, a description of the system architecture, including hardware and software data handling procedures may be necessary. Such a description should clearly establish the reasons why the system will not experience functional upset when exposed to these environments. Pin testing or single stroke cable bundle testing per Section 22 of DO-160D/ED-14D, is sufficient to demonstrate the system's ability to withstand the ETDs without component damage.

(v) Establish ETDs Using Existing System Data (Similarity)

Existing system data generated by test and/or analysis may be used to establish ETDs provided the system under consideration is similar to the system used to generate the data. Guidance in determining system similarity is given in Section 10a(1)(i).

(vi) Compliance Assessment

An assessment is required to determine the system's functional compatibility with the internal lightning environment, and must show the following.

- (A) The function on the aircraft must remain available during and after exposure to the indirect effects of lightning.
- (B) Any system interruption or susceptibility must be

evaluated to assure that there are no adverse effects on continued performance of the function and must be approved by the cognizant aviation certification authority.

- (C) The affected systems must automatically recover upon removal of the internal lightning environment unless this conflicts with other requirements of that system.
- (D) The equipment/system must tolerate the ETDLS, and the ATLs in the interconnecting wiring must be less than or equal to the TCLs.

(vii) Corrective Measures

Should the system fail to satisfy the certification requirements, a decision will be required on the corrective action to be taken. The resultant changes or modifications to the installation and/or the equipment may generate the need for additional testing/analysis. It may be necessary, therefore, to repeat the relevant equipment qualification testing/analysis and/or aircraft testing/analysis, in whole or in part, in order to satisfy the certification requirements. Modification of the equipment and/or installation may be necessary to achieve certification.

(2) Systems Performing Level A Display Functions

Figure 3 is a flow diagram showing possible routes to compliance for systems performing Level A Display functions. The objective of this approach is to demonstrate that the Level A function is maintained and the Level A system does not generate hazardously misleading information (HMI) when exposed to the indirect effects of lightning. In Figure 3, a review of any existing aircraft and/or system data is accomplished and a decision must be made on the direction the applicant chooses to achieve certification in each case.

(i) Similarity

Similarity may be used as the basis for certification without the

need for additional tests provided:

- only minimal differences exist between the previously certified system and installation and the system and installation to be certified, and
- there have been no unresolved in-service history of problems related to lightning strikes to the aircraft.

If there is uncertainty about the effects of the differences, additional tests and/or analysis should be conducted as necessary and appropriate to resolve the open issues.

Similarity may be used to verify compatibility of systems and equipment with ETDs, or compatibility of interconnecting wiring with TCLs. The former situation might occur when a previously tested system is to be certified in a new aircraft, and the latter situation may occur when a new system is to be installed in an existing aircraft using interconnecting wiring for which ATLs and TCLs are known.

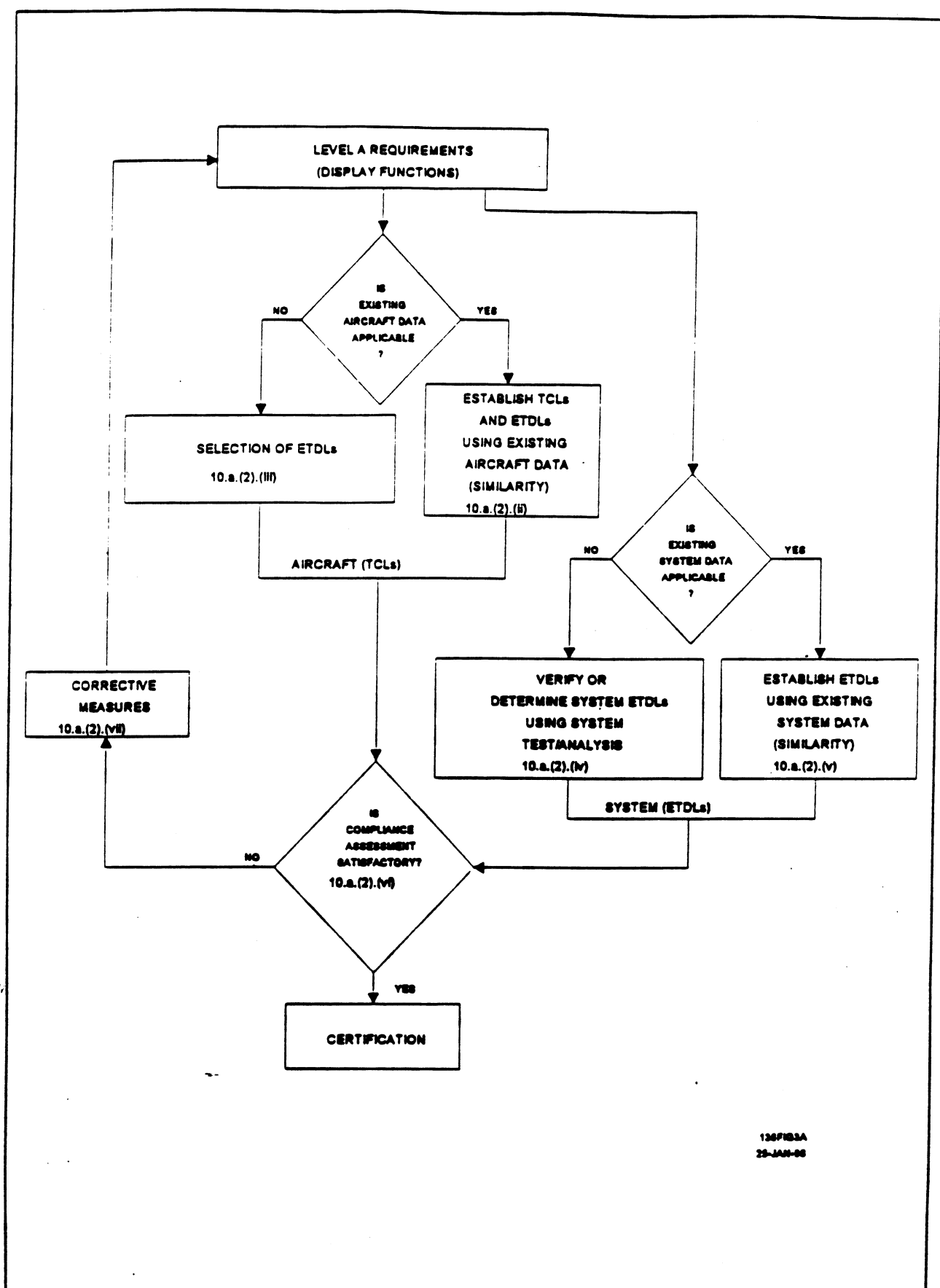


Figure 3 - Typical Iterative Process for Level A Requirements (Display Functions)

Similarity requires an evaluation of both the system and installation differences which may adversely affect the system susceptibility. An assessment of a new installation should consider differences affecting the internal lightning environment of the aircraft and its effects on the system. The assessment may cover:

- (A) the aircraft type, equipment locations, airframe construction, and apertures which could affect attenuation of the external lightning environment;
- (B) the system interfaces, wiring size and routing, connectors, whether parallel or twisted wires, and cable shielding;
- (C) grounding and bonding;
- (D) system modification status including software, firmware, and hardware.

Systems previously certified by test or analysis may be transferable to other applications. Every system needs to be assessed even though it may utilize equipment and installation techniques which have been the subject of a previous certification.

The use of similarity for Level A Display systems requires that the applicant show that any differences of either the system or its installation cause MINIMAL ADVERSE CHANGES on the TCL and ETDL values. If minimal adverse changes are discovered, then those differences should be discussed with the cognizant aviation certification authority.

Similarity is NOT APPLICABLE for a combination of a new aircraft design and a new system design.

(ii) Establish TCLs and ETDLs Using Existing Aircraft Data (Similarity)

This option provides a means of using existing aircraft data on a similar type aircraft to establish TCLs for the intended

installation. This may be accomplished provided the aircraft and system installation under consideration are similar to the aircraft and system installation used to generate the data. Guidance in determining aircraft similarity is given in 10.a.(2).(i).

(iii) Selection of ETDs

This section examines two options:

- 1) Determine ATs, Tcs, and ETDs using whole aircraft test/analysis.

This option is the same method which is used for control systems and is outlined in Section 10a(1)(ii).

- 2) Selection of ETDs per DO-160D/ED-14D.

This option provides a means of selecting the ETDs for the equipment without the benefit of specific aircraft test data. Section 22 of DO-160D/ED-14D, tables 22-2 and 22-3 provide predicted ETDs. It must be noted, however, that substantiating evidence must show all the factors necessary to enable comparison of the ETDs selected from DO-160D/ED-14D. Section 22, to the proposed aircraft installation. Each ETD level selected should reflect all the significant aspects of the aircraft installation.

The following guidelines are included to assist the applicant in the proper selection of ETDs given in DO-160D/ED-14D. It should be noted that different ETD levels may be appropriate for different waveforms, reflecting proportionately higher or lower structural resistance voltages as compared with induced voltages due to changing magnetic fields. In such cases, the appropriate levels should be used.

Level 5: This level can be used when the equipment under consideration, or the cable bundle, or interfaces to/from the equipment are located in very severe

electromagnetic environments which are defined as areas with composite materials demonstrating poor shielding effectiveness, areas where there is no guarantee of structural bonding, and other open areas where minimal shielding is provided. This level may also be used when a broad range of installations is to be covered. Note that in some cases (essentially high current density regions on mixed conductivity structures such as wing tips, engine nacelle fin, etc) where the wiring may divert some of the lightning current, higher ETDL's may be appropriate unless design measures are applied to reduce them.

Level 4: This level can be used when the equipment under consideration, or the cable bundle, or interfaces to/from the equipment are located in severe electromagnetic areas which are defined as areas outside the fuselage such as wings, fairings, wheel wells, pylons, control surfaces, etc. This definition is not appropriate for equipment installations more appropriately described by the definition of Level 5.

Level 3: This level can be used when the equipment under consideration, all interfaces to/from the equipment, and the cable bundle are contained entirely within a moderate electromagnetic environment which is defined as the inside of a metallic aircraft structure or composite aircraft structure demonstrating equivalent shielding effectiveness, without particular shielding enhancement measures. Examples of such an environment are avionics bays not enclosed by bulkheads, cockpit areas, and locations with large apertures, i.e., doors without EMI gaskets, windows, access panels, etc. Current carrying conductors in this environment such as hydraulic tubing, control cables, cable bundles, metal cable trays, etc., are not necessarily electrically grounded at bulkheads. When a small number of wires

exit the environment, either a higher level (i.e. Level 4 or 5) should be used for these interfaces or additional protection for these wires should be provided. This definition is not appropriate for equipment installations more appropriately described by the definitions of Levels 4 and 5.

Level 2: This level can be used when the equipment under consideration, all interfaces to/from the equipment, and the cable bundle are contained entirely within a partially protected environment which is defined as the inside of a metallic aircraft structure or composite aircraft structure demonstrating equivalent shielding effectiveness, where measures have been taken to reduce the electromagnetic coupling onto cables. Cable bundles in this environment passing through bulkhead(s) have shields terminated at the bulkhead connector. When a small number of wires exit the environment, either a higher level (i.e. Level 3 or 4) should be used or additional protection for these wires should be provided. Cable bundles are installed close to the ground plane and take advantage of other inherent shielding characteristics provided by metallic structures. Current carrying conductors such as hydraulic tubing, cables, metal cable trays, etc., are electrically grounded at all bulkheads. This definition is not appropriate for equipment installations more appropriately described by the definitions of Levels 3, 4 and 5.

Level 1: This level can be used when the equipment under consideration, all interfaces to/from equipment, and the cable bundles are contained entirely within a well protected environment which is defined as an electromagnetically enclosed area which is not subjected to direct attachment of lightning strikes. This definition is not appropriate for equipment

installations more appropriately described by the definitions of Levels 2, 3, 4, and 5.

(iv) Verify or Determine System ETDs Using System Test/Analysis

The ETDs selected are then used in the application of the multiple stroke and multiple burst environments as defined in the AC/AMJ 20-TBD, Aircraft Lightning Environment and Related Test Waveform Standard and tested in accordance with procedures described in the AC/AMJ 20-TBD, Aircraft Lightning Test Standard. For pin and single stroke cable bundle testing, the system should be tested in accordance with procedures described in DO-160D/ED-14D, Section 22. Whenever cable bundle test methods are used, the system should be tested in an operational state. Pin testing or single stroke cable bundle testing per Section 22 of DO-160D/ED-14D, is sufficient to demonstrate the system's ability to withstand the ETDs without component damage.

(v) Establish ETDs Using Existing System Data (Similarity)

Existing system data generated by test and/or analysis may be used to establish ETDs provided the system under consideration is similar to the system used to generate the data. Guidance in determining system similarity is given in 10.a.(2).(i).

(vi) Compliance Assessment

An assessment is required to determine the system's functional compatibility with the effects of the internal lightning environment and must show the following:

- (A) The function on the aircraft must remain available during and after exposure to the indirect effects of lightning.
- (B) Any system interruption or susceptibility must be evaluated to assure that there are no adverse effects on continued performance of the function and must be approved

by the cognizant aviation certification authority.

- (C) The affected systems must automatically recover upon removal of the internal lightning environment unless this conflicts with other requirements of that system.
- (D) The equipment/system must tolerate the selected ETDs, and the implied TCLs must be appropriate for the specific aircraft installation.

(vii) Corrective Measures

Should the system fail to satisfy the certification requirements, a decision will be required on the corrective action to be taken. The resultant changes or modifications to the installation and/or the equipment may generate the need for additional testing/analysis. It may be necessary, therefore, to repeat the relevant equipment qualification testing/analysis and/or aircraft testing/analysis, in whole or in part, in order to satisfy the certification requirements. Modification of the equipment and/or installation may be necessary to achieve certification.

b. Level B and C Requirements

Functions performed by electrical and electronic systems whose failure could cause a hazardous/severe-major effect or major effect would require protection from the indirect effects of lightning to the extent that, when the equipment of which the system is comprised, is exposed to a defined test level, the electrical and electronic systems that perform the functions must not be damaged and the functions must be recoverable in a timely manner.

Systems requiring Level B or Level C protection, by the nature of the functions being performed, may be qualified using the methods defined in DO-160D/ED-14D, Section 22. Multiple stroke and multiple burst testing is not required if an analysis shows: (1) The equipment is not susceptible to

upset or; (2) The equipment may be susceptible to upset, but a reset capability exists that will recover the function in a timely manner. Possible routes to compliance are shown in Figure 4.

As an alternative for demonstrating compliance to lightning protection for Level B and Level C systems, Aircraft Flight Manual limitations may be applied on non-Part 25 aircraft that are limited to VFR flight conditions. For aircraft that are limited to VFR flight conditions, the aviation certification authority may accept the probability of exposure and/or loss of Level B and Level C functions with an Aircraft Flight Manual restriction, providing that an acceptable level of safety for the type aircraft and its operation can be demonstrated. The Type Certification Data Sheet, Aircraft Flight Manual (AFM), Supplemental AFM, and/or Placard should contain the statement as follows: "This aircraft is only approved for VFR flight conditions and must not be operated into known or forecast lightning conditions"

(1) Similarity

In any similarity evaluation, all changes to the system or its installation must be assessed for their effect on a system to meet the certification requirements. Unless the system used as the certification basis for similarity has been demonstrated to withstand the testing defined in 10.b.(4), a review of the service experience and modification history of the system should be conducted for evidence of possible unresolved susceptibilities to the indirect effects of lightning. A qualitative demonstration of similarity for Level B and C systems rather than a quantitative assessment as defined for Level A Control and Display systems is sufficient.

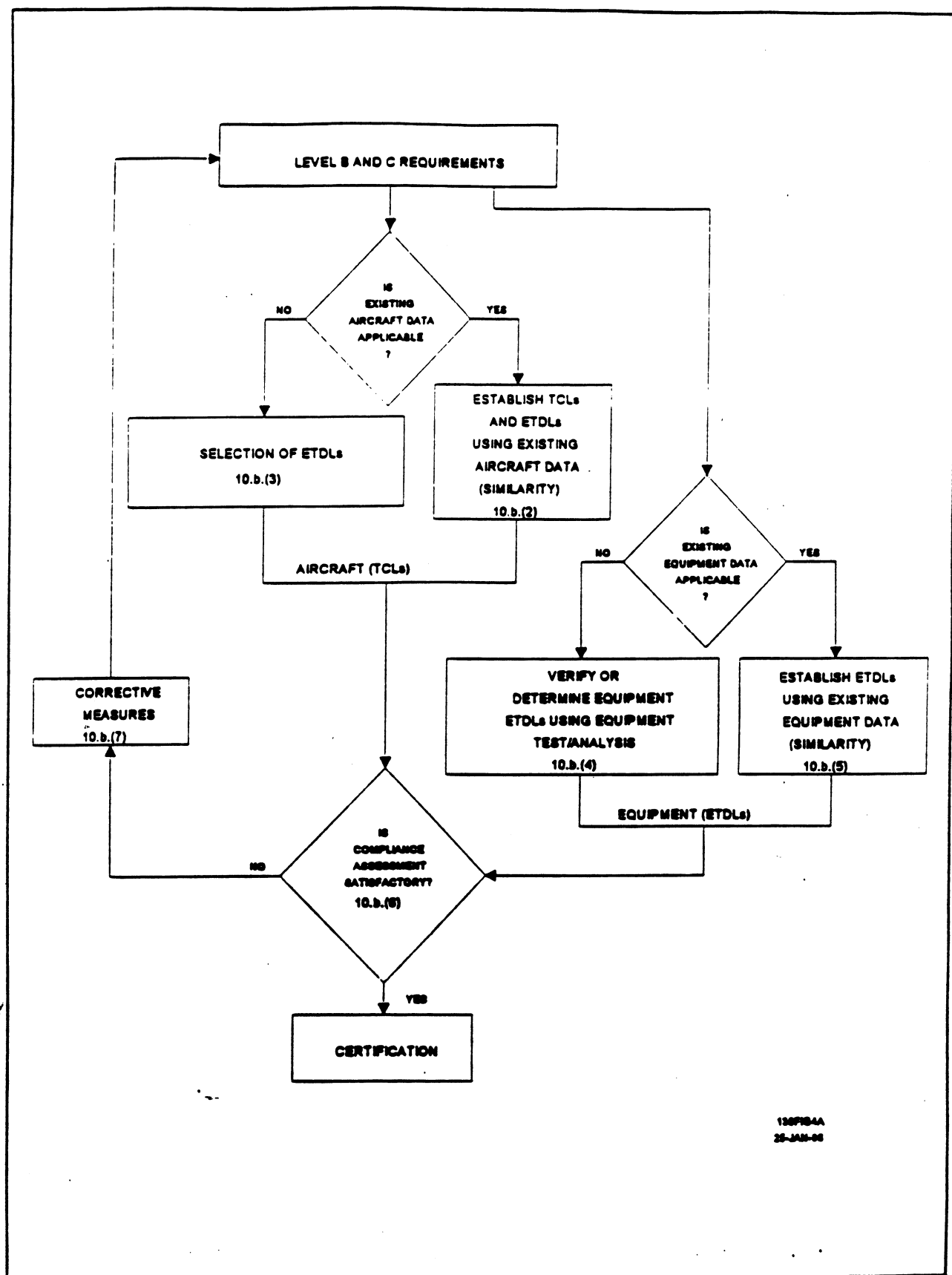
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Figure 4 - Typical Iterative Process for Level B and C Requirements

(2) Establish TCLs and ETDs Using Existing Aircraft Data (Similarity)

This option provides a means of using existing aircraft data on a similar type aircraft to establish TCLs for the intended installation. This may be accomplished provided the aircraft and system installation under consideration are similar to the aircraft and system installation used to generate the data. Guidance in determining aircraft similarity is given in 10.a.(1).(i) and 10.a.(2).(i).

(3) Selection of ETDs

The aircraft test or analysis methods used to determine the ETDs for Level A systems are acceptable for determination of ETDs for Level B and C systems. Alternately, Level 3 as defined in DO-160D/ED-14D, Section 22 may be used for most Level B systems. For Level B systems and associated wiring installed in more severe electromagnetic environments such as areas external to the fuselage, areas with composite structures demonstrating poor shielding effectiveness, and other open areas, select a level appropriate to the environment. [See paragraph 10.a.(2).(iii).]

Level 2 as defined in DO-160D/ED-14D, Section 22, may be used for most Level C systems. For Level C systems installed in more severe electromagnetic environments such as areas external to the fuselage, areas with composite structures demonstrating poor shielding effectiveness, and other open areas, use Level 3. If a group of Level C systems are installed in more severe electromagnetic environments, the FHA should consider the simultaneous failure of that group as a result of a lightning strike. If the combined failure of that group is classified as Hazardous/Severe-major, the ETD for a number (determined by the FHA) of Level C systems in that group should be selected as if they were Level B systems.

(4) Determine Equipment ETDs Using Equipment Test/Analysis

Perform equipment testing in accordance with the procedures of DO-160D/ED-14D, Section 22, to ETDs determined in 10.b.(2) [i.e., TCLs +

margin (if any)] or 10.b.(3).

(5) Establish ETDs Using Existing Equipment Data (Similarity)

Existing system data generated by test and/or analysis may be used to establish ETDs provided the system under consideration is similar to the system used to generate the data. Guidance in determining similarity is given in 10.b.(1).

(6) Compliance Assessment

The test results should be reviewed. The cause(s) of any result(s) that do not meet the acceptance criteria must be corrected prior to certification.

(7) Corrective Measures

Should the system fail to satisfy the certification requirements, a decision will be required on the corrective action to be taken. The resultant changes or modifications to the installation and/or the equipment may generate the need for additional testing/analysis. It may be necessary, therefore, to repeat the relevant equipment qualification testing/analysis and/or aircraft testing/analysis, in whole or in part, in order to satisfy the certification requirements. Modification of the equipment and/or installation may be necessary to achieve certification.

c. Level D and E Requirements

No further applications of these regulations are required.

11. MAINTENANCE AND SURVEILLANCE. The minimum maintenance required to support certification must be identified in instructions for continued airworthiness (e.g., XX.1529, MRB, MMEL, etc.). When dedicated protection devices or specific techniques are required to provide the protection for a system or equipment on an installation, the periodic/conditional maintenance and/or requirements for surveillance of these devices or techniques should be

defined to ensure the protection integrity is not degraded in service. In addition, the use of devices which may degrade with time due to corrosion, fretting, flexing cycles or other causes should be avoided where possible or dedicated replacement times identified.

Aircraft/system modifications need to be assessed for the impact of changes to the protection level against the direct and indirect effects of lightning. In principle, this assessment will be based on analysis and/or measurement.

The techniques and time intervals for evaluating or monitoring the integrity of the system protection should be defined. Built in test equipment, resistance measurements, continuity checks of the entire system or other means need to be identified to provide periodic/conditional surveillance of the system integrity.

The User's Manual provides further information on these topics.

APPENDIX I - Glossary of Terms

The following are definitions of terms as they are utilized in this document.

Actual Transient Level (ATL). The actual transient level is the level of transient voltage and/or current which appears at the equipment interfaces as a result of the external environment. This level may be less than or equal to the transient control level but should not be greater.

Aperture. An electromagnetically transparent opening.

Attachment Point. A point of contact of the lightning flash with the aircraft.

Component Damage. That condition where the electrical characteristics of a circuit component are permanently altered so that it no longer performs to its specifications.

Continued Safe Flight and Landing. This phrase means that the aircraft is capable of safely aborting or continuing a takeoff or continuing controlled flight and landing, possibly using emergency procedures but without requiring

exceptional pilot skill or strength. Some aircraft damage may occur as a result of the failure condition or upon landing. For airplanes, the safe landing must be accomplished at a suitable airport. For rotorcraft, this means maintaining the ability of the rotorcraft to cope with adverse operating conditions and to land safely at a suitable site. See the AC/AMJ XX.1309

Control Function. A function that has some automated influence on a system (i.e., engine control system, flight control system) and whose failure would prevent the continued safe flight and landing of the aircraft.

Direct Effects. Any physical damage to the aircraft and/or electrical/electronic systems due to the direct attachment of the lightning channel. This includes tearing, bending, burning, vaporization, or blasting of aircraft surfaces/structures and damage to electrical/electronic systems.

Display Systems. Those Flight, Navigation and Power Plant Instruments required by FAR XX.1303 and XX.1305

Equipment Interface. A location on an equipment boundary where connection is made to the other components of the system of which it is part. It may be an individual wire connection to an electrical/electronic item, or wire bundles that interconnect equipment. It is at the equipment interface that the equipment transient design level (ETDL) and transient control level (TCL) are defined and where the actual transient level (ATL) should be identified.

Equipment Transient Design Level (ETDL). The peak amplitude of transients to which the equipment is qualified.

Equipment Transient Susceptibility Level (ETSL). The transient peak amplitude which will result in damage or upset to the system components.

External Environment. Characterization of the natural lightning environment for design and certification purposes as defined in the AC/AMJ 20-TBD, Aircraft Lightning Environment and Related Test Waveform Standard.

Indirect Effects. Electrical transients induced by lightning in aircraft electric circuits.

Internal Environment. The fields and structural IR potentials inside the

aircraft produced by the external environment.

Lightning Flash. The total lightning event. It may occur within a cloud, between clouds, or between a cloud and ground. It can consist of one or more return strokes, plus intermediate or continuing currents.

Lightning Strike. Any attachment of the lightning flash to the aircraft.

Lightning Strike Zones. Aircraft surface areas and structures classified according to the possibility of lightning attachment, dwell time, and current conduction. See the AC/AMJ 20-TBD, Aircraft Lightning Zoning Standard.

Lightning Stroke (Return Stroke). A lightning current surge that occurs when the lightning leader makes contact with the ground or another charge center.

Margin. The difference between the equipment transient design level and the transient control level.

Multiple Burst. A randomly spaced series of bursts of short duration, low amplitude current pulses, with each pulse characterized by rapidly changing currents (i.e., high di/dt 's). These bursts may result from lightning leader progression or branching, and are associated with the cloud-to-cloud and intra-cloud flashes. The multiple bursts appear to be most intense at the time of initial leader attachment to the aircraft. See AC/AMJ 20-TBD Aircraft Lightning Environment and Related Test Waveform Standard.

Multiple Stroke. Two or more lightning return strokes occurring during a single lightning flash. See AC/AMJ 20-TBD, Aircraft Lightning Environment and Related Test Waveform Standard.

Return Stroke. (see Lightning Stroke)

Structural IR Voltage. The portion of the induced voltage resulting from the product of the distributed lightning current (I) and the resistance (R) of the aircraft skin or structure.

Swept Channel. The lightning channel relative to the aircraft, which results in a series of successive attachments due to sweeping of the flash across the aircraft by the motion of the aircraft.

System Functional Upset. An impairment of system operation, either permanent or momentary (e.g., a change of digital or analog state) which may or may not require manual reset.

Transient Control Level (TCL). The transient control level is the maximum allowable level of transients appearing at the equipment interfaces as a result of the defined external environment.

Upset. (See System Functional Upset)

